

NASA's X2000 Program – an Institutional Approach to Enabling Smaller Spacecraft¹

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Abstract

The number of NASA science missions per year is increasing from less than one to more than six. At the same time, individual mission budgets are smaller and cannot afford their own dedicated technology developments. In response to this, NASA has formed the X2000 Program. This program, which is divided into a set of subsequent “deliveries” will provide the basic avionics, power, communications, and software capability for future science missions. X2000 First Delivery, which will be completed in early 2001, will provide a full-functioned one MRAD tolerant flight computer, power switching electronics, a highly efficient radioisotope power source, and a transponder that provides high-level services at both 8.4 GHz and 32 GHz bands. The X2000 Second Delivery, which will be completed in the 2003 time frame, will enable complete spacecraft in the 10-50 kg class. All capabilities delivered by the X2000 program will be commercialized within the US and therefore will be available for others to use. Although the immediate customers for these technologies are deep space missions, most of the capabilities being delivered are generic in nature and will be equally applicable to Earth Observation missions.

1. Introduction

Since the robotic exploration of deep space began in the 1960s, it has been characterized by a space mission every three to five years. These were major endeavors, each with a budget of about one billion 1998 US dollars. This era gave us Voyager, Galileo, and Cassini, for example. Each of these missions had sufficient funding to develop and infuse whatever new technology was required to achieve the mission's objectives. However, because these missions came infrequently, there was little inheritance of technology from one to the next.

NASA has recently embarked on an era of *faster-better-cheaper* missions. These missions occur much more frequently. There have been six deep space launches in the last

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year, for example. NASA's goal is to have an average of one launch each month. These missions, however, have much less funding – about \$200M each in 1998 US dollars. The spacecraft are much smaller and carry fewer science instruments.

One consequence of this is that individual missions can no longer afford large investments in technology development. Since it is exactly these new technologies that enable such missions to be accomplished at low cost, another way had to be found to infuse technology. This has led to the establishment of NASA institutional technology development programs, including the X2000 Program.

2. The X2000 Program

NASA's X2000 Program was created in 1997 by the NASA Office of Space Science and is managed at NASA's Jet Propulsion Laboratory (JPL.) The program was chartered to infuse new technologies that will enable new, lower-cost and higher performance spacecraft, particularly for the exploration of the outer planets. The X2000 program consists of two major parts: a long-term technology development effort in specific areas not covered by other NASA technology programs, and a set of *deliveries* of flight-qualified new technology capabilities that are ready to be used by flight missions.

The long-term technology developments include the Center for Integrated Space Microsystems (CISM) [1] and the Advanced Radioisotope Power Source (ARPS) [2]. The CISM is responsible for advances in space microelectronics and advanced computing methodologies. The ARPS effort develops new power sources for deep space to replace the current Radioisotope Thermoelectric Generators that are used on today's outer planet missions.

The deliveries are formed approximately every three years. The output of a delivery is a set of integrated, flight-qualified, capabilities that have been commercialized. Deliveries are managed as flight projects. This means they have a well-defined set of requirements, a fixed budget, and a schedule for completion. This allows any future mission to use these capabilities in their planning and execution.

3. X2000 First Delivery Project

In 1998, the X2000 Program formed its first delivery, called the First Delivery Project (FDP) [3]. FDP capabilities will be delivered in 2000. Many deep space missions that will launch in 2003 or later are planning to use capabilities from FDP. These missions include Europa Orbiter, Pluto/Kuiper Express, Solar Probe, Champollion (DS-4,) Mars Sample Return, and several Discovery class missions. Europa Orbiter and Champollion have a special relationship with X2000 FDP. Because they launch before the others, X2000 capabilities are in their critical path for development.

FDP is developing an integrated set of flight avionics that will be radiation hardened to the one MRAD level. This level of radiation-hardening is required to achieve the goals of the Europa Orbiter mission [4]. A new avionics architecture has been developed that extends the personal computer revolution into space. FDP is developing a plug-and-play set of avionics slices. Each Compact Peripheral Computer Interconnect (CPCI) 160 x 100 mm slice provides some basic functionality. A spacecraft designer can mix and

match slices to provide desired system capabilities. There are slices for computer systems, long and short term memory, power management, and interfaces to spacecraft instruments. The slices can communicate with each other via standard networking protocols using either a Computer Peripheral Interconnect (PCI) or IEEE 1394 bus .

As part of the FDP, a 100 million instruction-per-second (MIPS) flight computer will be developed. This will allow substantial computational capabilities in deep space for the first time.

A new software architecture, called the Mission Data System (MDS) is being developed by FDP to support the new avionics [5]. The MDS will include both flight and ground software in a seamless suite. The MDS will manage spacecraft and ground systems by controlling their state. Goal-oriented commands will be sent to systems, which will be capable of determining how to modify their state to achieve these goals. Currently, in order to have a spacecraft take a picture of a target, a large set of low-level commands is communicated to the spacecraft to execute a turn, point in a given direction, open a camera lens, acquire data, format the data, and send it back to Earth. Using the MDS, there will be a single goal-oriented command to take a picture of a target. The various spacecraft systems, including the attitude system, the camera, and the telemetry system, will know how to achieve these goals, without disturbing other goals that may also have been requested.

The MDS and the flight avionics will provide the basic capabilities for spacecraft automation, science data processing, and autonomous navigation. Individual flight missions will then build upon this capability to achieve their specific objectives. In order to achieve a smooth transition, many mission engineers also work with the X2000 FDP team.

In addition, FDP will provide a generic communications transponding capability at both the current 8.4 GHz deep space band and the future 32 GHz band. Only the transponder will be provided by FDP. The front-end communication systems (which tend to differ from mission to mission) will be added by the individual missions.

Although FDP capabilities were chosen to enable outer planets missions, many of these capabilities will also be suitable for use on Earth-orbiters. These include the entire avionics package and the Mission Data System. JPL has begun working with NASA's Goddard Space Flight Center to understand how these capabilities (and those in future deliveries) can be applied to near-Earth spacecraft.

4. Second Delivery

Last summer, the X2000 program began making choices concerning X2000 Second Delivery. Considerable effort was spent examining technologies that might mature in the 2003 time frame. Since there are few missions that launch after 2005 that are well defined, several possible mission scenarios were studied using JPL's Team-X [6] activity. Team-X consists of a group of experts in various spacecraft capabilities, a facility for collaborative engineering studies, and a database of possible future capabilities and costs. Team-X is usually used to prepare mission proposals. Here Team-X was used to study the impact of new technologies on possible future missions.

Among the mission scenarios that were studied in Team-X were a Europa lander, a Pluto lander, a Neptune orbiter, and aerobots (devices that maneuver in planetary atmospheres.) Other design work was conducted outside of Team-X (within the X2000 Future Deliveries Design Team) to further understand the possibilities for Second Delivery.

When these studies were completed, NASA and JPL decided to focus the Second Delivery on enabling a generic micro spacecraft capability. These micro spacecraft could be as small as 10-50 kg. They could be fully functional spacecraft, daughter spacecraft (that would be deployed from larger vehicles for special purposes,) aerobot gondolas, or rover systems.

There are four major new technology capabilities that are being considered for Second Delivery.

First, there will be a further reduction in mass, power, and volume of the basic avionics capability. In particular, an order of magnitude reduction in mass beyond FDP is expected without any degradation in performance. In fact, an increase in performance of the system is likely. The architecture will build upon the plug-and-play architecture of FDP.

Second, a micro propulsion capability for attitude and control of these micro spacecraft will be developed. The standard propulsion techniques available today are too large and too powerful for such small spacecraft.

Third, a moderate to high bandwidth (from deep space) optical communications terminal will be developed. Analyses performed by JPL's Telecommunication and Mission Operations Directorate have shown a good business case for operational optical communications in the 2010 time frame [7]. In order to enable these cost savings, the first terminals must be developed in the Second Delivery era. The optical terminal will double as a high-resolution, narrow-field spacecraft imager. This dual-use technology will reduce the effective mass of the communication to close to zero. In a similar way, we will investigate using a star-tracker to double as a wide-field imager.

Fourth, a communications relay capability will be studied. The trend in deep space exploration (and in many near-Earth applications) is toward systems of spacecraft that work together to achieve their goals. This relay capability will provide communication between spacecraft in a constellation, between landed elements and orbiters, between rovers and base stations, and between aerobots and other devices.

JPL and GSFC have begun working together, even before these decisions were made, to allow as much of the Second Delivery capability as possible to be used by near-Earth spacecraft.

5. Conclusion

New technology is critical to the future of space exploration, but individual missions can no longer afford large individual technology programs. The X2000 Program is therefore extremely important to achieving NASA's goal of a dozen faster-better-cheaper missions to deep space each year. Most of the capabilities being developed in X2000 deliveries

are equally applicable to near-Earth spacecraft. By working together with the near-Earth spacecraft community, we can insure the maximum use of these new technologies.

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